U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-258 799-T

# Vertical Structure of the Turbulence Energy above an Agitated Surface

Environmental Protection Agency, Research Triangle Park, N C

1971

300024

PB 258 799-T

EPA-TR-647-73G

APTIC 10 37
4

# VERTICAL STRUCTURE OF THE TURBULENCE ENERGY ABOVE AN AGITATED SURFACE

[Vertikal'naya struktura energii turbulentnosti nad vznolnovannoy poverkhnost'yu]

Ye. L. Genikhovich and L. Yu. Preobrazhenskiy

Atmospheric diffusion and air pollution,
1971, pp. 116 - 120

Translated for EPA by
SCITRAN (SCIENTIFIC TRANSLATION SERVICE)
SANTA BARBARA, CALIFORNIA

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

| BIBLIOGRAPHIC DATA SHEET | 1. Report No. EPA TR73-647G | 2. | 3. Recipient's Accession No. |
|---|---|---|---|
| 4. Title and Subtitle: Vertical structure of the turbulence energy above an agitated surface | | | 5. Report Date: 1971<br>6. |
| 7. Author(s): Ye. L. Genikhovich and L. Yu. Preobrazhenskiy | | | 8. Performing Organization Rept. No. |
| 9. Performing Organization Name and Address: TRANSLATED FROM RUSSIAN BY EPA | | | 10. Project/Task/Work Unit No.<br>11. Contract/Grant No. |
| 12. Sponsoring Organization Name and Address: Translation Service, Office of Administration - Library, Research Triangle Park, NC 27711 | | | 13. Type of Report & Period Covered<br>14. |

15. Supplementary Notes

ATMOSPHERIC DIFFUSION AND AIR POLLUTION 1971, pp. 116-120

16. Abstracts

17. Key Words and Document Analysis. 17a. Descriptors

EPAISD

17b. Identifiers/Open-Ended Terms

METEOROLOGY

17c. COSATI Field/Group 04B 55C

PRICES SUBJECT TO CHANGE

| 18. Availability Statement: THIS TRANSLATION WAS MADE FROM A NON-COPYRIGHTED TEXT | 19. Security Class (This Report): UNCLASSIFIED | 21. No. of Pages: 8 |
|---|---|---|
| i. | 20. Security Class (This Page): UNCLASSIFIED | 22. Price: 3.50-3.00 |



USCOMM-DC 40329-P71

# VERTICAL STRUCTURE OF THE TURBULENCE ENERGY ABOVE AN AGITATED SURFACE

Ye. L. Genikhovich and L. Yu. Preobrazhenskiy

Experiments involving study of the wind structure above the sea conducted in recent years have made it possible to determine the characteristics of turbulence in the layer near the water. The results obtained indicate significant differences in the structure of the turbulent flow above the sea in comparison with the layer of the atmosphere near the ground. In particular, when undifferentiated stratification is present, the ratio of the energy of the turbulence to the square of the dynamic velocity is not a universal constant [3, 4, 8]. However, measurements that have been conducted do not allow a sufficiently detailed description to be given of the vertical distribution of the turbulence energy which must depend on the characteristics of the waves. A confirmation of this may be found in the special features of the energy spectra and in the nature of the correlation functions of the wind speed pulsations [1, 3, 8].

The pulsations in the longitudinal u' and vertical w' components of the wind speed were measured on marine expeditions of the MGO in the North Atlantic from a floating Frud spar buoy and in the Baltic Sea from a structure mounted on the bottom. The measurements were conducted by means of thermoanemometers mounted at the 1, 2 and 5 meter levels. As indicated by the data obtained, the changes in the longitudinal and vertical velocity components $\sigma_u^2$ and $\sigma_w^2$ of the wind depend on the characteristics of the waves and on the height above mean sea level.

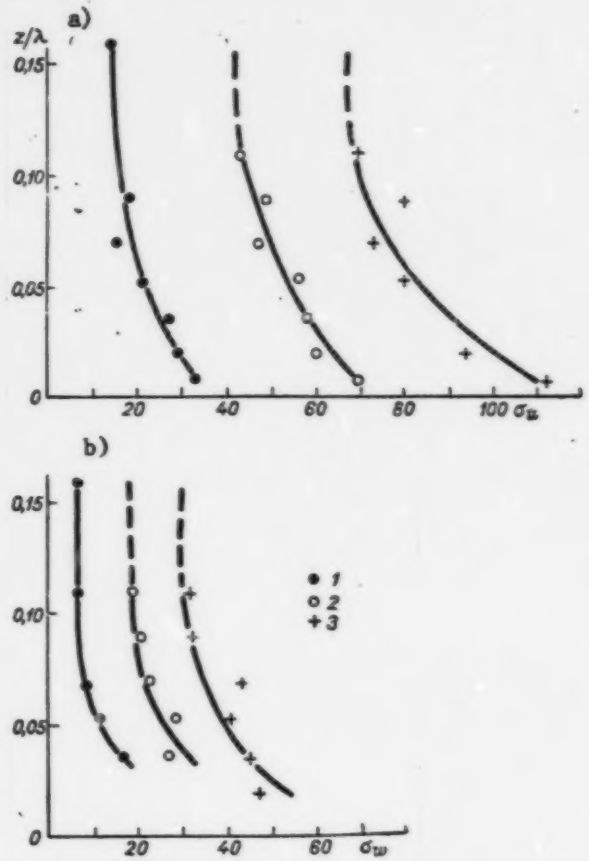


Figure 1. Vertical profiles of mean square pulsations in longitudinal (a) and vertical (b) velocity components of wind above the sea at various $v_*$. (1)- $v_*$ = 0-9 cm/sec; (2)- $v_*$ = 10-19 cm/sec; (3)- $v_*$ = 20-40 cm/sec.

For the sake of an example, Figure 1 shows the vertical profiles $\sigma_u$ and $\sigma_w$ as a function of a dimensionless altitude $z/\lambda$, where $\lambda$ is the mean wave length of 50% coverage, for values of the dynamic velocity $v_*$ 0-9, 10-19 and 20-40 cm/sec. (This approximately corresponds to the aerodynimically smooth intermediate and rough modes of flow over a water surface [5].)

These results, as well as the data from spectra measurements [3], indicate that, as the flow passes over a rough surface, there is an additional generation

of turbulent energy associated with the curvature of the flow lines and a charge in the curvature of the velocity profile near the boundary. It is advantageous to construct a simple mathematical model of this process.

In order to describe the nature of the air flow near a curved subjacent surface, we must change to flow coordinates (flow function and velocity potential of potential flow in the area in question) in the equations of motion. The resultant equations are simplified by usual boundary layer theory methods [2], and in the case of slight curvature it can be shown that in the first approximation the wind speed at a certain level above the surface depends only on the value of the flow function of the potential flow at this level. In this connection, as the velocity component along the flow lines, we shall use the very simple model

$$u = \frac{v_*}{\varkappa} \ln \frac{\psi}{\psi_0}, \tag{1}$$

where $\psi$ is the value of the current function, $\psi_0$ is the flow roughness of the subjacent surface and $\kappa = 0.4$ is the Karman constant.

The nature of the vertical distribution of the turbulent energy b averaged over time may be determined from the balance equation of turbulent energy.

Considering the rough surface to be uniform in the direction perpendicular to the wind and assuming isotropy for the coefficient of turbulent exchange k, we can write the transformation term of turbulent energy balance Tr as follows:

$$\mathrm{Tr} = k\left[\left(\frac{\partial u}{\partial z}\right)^2 + 4\left(\frac{\partial u}{\partial x}\right)^2\right]. \tag{2}$$

We know (see for example [8]), that in the case of potential flow above a traveling sinusiodal surface the current function will have the form

$$\psi = u_\infty \left[z + ae^{-\frac{2\pi z}{\lambda}} \cos\left(\frac{2\pi x}{\lambda} - \omega t\right)\right], \tag{3}$$

where $u_\infty$ is the speed of an undisturbed incident flow, a is the amplitude, $\lambda$ is the length and $\omega$ is the cyclic frequency of the traveling wave. If (1)

and (3) are substituted into (2) and the resultant expression is averaged over time, we have the relationship

$$\mathrm{Tr} = k u_\infty^2 \left(\frac{du}{d\psi}\right)^2 \left(1 + \frac{10\,\pi^2 a^2}{\lambda^2} e^{-\frac{4\pi z}{\lambda}}\right). \tag{4}$$

For the coefficient of turbulent exchange, we will have the following model which agrees with (1)

$$k = \varkappa v_* \frac{\psi}{u_\infty}, \tag{5}$$

from which in particular

$$k u_\infty \left(\frac{du}{d\psi}\right) = v_*^2. \tag{6}$$

Disregarding the diffusion term, we can write the balance equation for turbulent energy in the form

$$\mathrm{Tr} = \mathrm{Di}. \tag{7}$$

and we will determine the dissipated term Di by using the Kilmogorov formula

$$\mathrm{Di} = \frac{cb^2}{k}, \tag{8}$$

where, according to [7], c = 0.046. Then from (4), (6) and (8) we will obtain the final expression for the turbulent energy

$$\frac{b}{v_*^2} = \frac{1}{\sqrt{c}} \left(1 + 10\,\frac{\pi^2 a^2}{\lambda^2} e^{-\frac{4\pi z}{\lambda}}\right)^{\frac{1}{2}}. \tag{9}$$

It follows from equation (9) that the turbulent energy b is proportional to the dynamic velocity $v_*$ and it decreases with increasing distance from the interface.

However, the numerical coefficients which are used in this expression are determined on the basis of a rough model of flow in which such factors as the non-sinusiodal shape of a wavy surface, transformation of the velocity profile along an individual wave, and the possible change in dynamic velocity $v_*$ which is related to this are not taken into account. Therefore, we shall

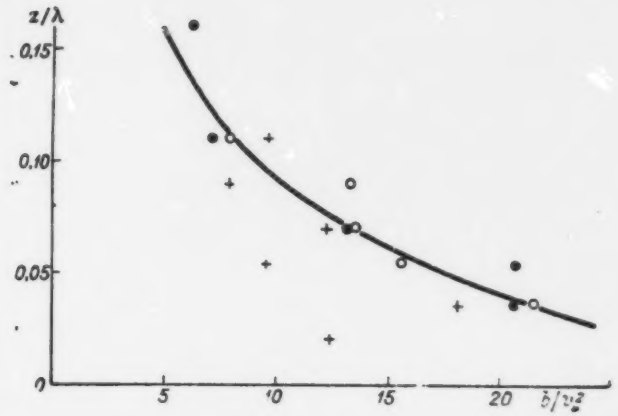


Figure 2. Vertical distribution of turbulent energy in the layer near the water [curve calculated on the basis of formula (10)].

● - $v_*$ = 0-9 cm/sec; o - $v_*$ = 10-19 cm/sec; + - $v_*$ = 12-40 cm/sec.

assume that the measurement of the turbulent energy with altitude is described by a relationship of type (9)

$$\frac{b}{v_*^2} = \frac{1}{\sqrt{c}}\left(1 + A\frac{a^2}{\lambda^2}\, e^{-B\frac{z}{\lambda}}\right)^{\frac{1}{2}}, \qquad (10)$$

whose coefficients are determined from the experimental graph (Figure 2) in which the dependence of $b/v_*^2$ on dimensionless altitude $z/\lambda$ is shown. The value b is determined by the formula

$$b = \frac{2\sigma_u^2 + \sigma_w^2}{2}.$$

A curve calculated on the basis of empirical values of the constant $A = 1 \cdot 10^5$ B = 32 is shown in this same diagram, with the ratio $a/\lambda$ being assumed equal to $0.25 \cdot 10^{-1}$, which corresponds to the curvature of large ocean waves. The comparison of formulas (9) and (10) shows that in the case of real flows the damping rate of boundary disturbances with altitude is clearly greater than what would be predicted by the theory of potential flows. Hence, model (1) for wind speed may be considered satisfactory if the coefficient $2\pi$ in the exponent in formula (3) is replaced by a larger value.

## REFERENCES


1. Byshev, V. I. and O. A. Kuznetsov. Structural Characteristics of Atmospheric Turbulence in the Layer Near the Water Above the Open Sea. Izvestiya AN SSSR, Fizika Atmosfery i Okeana, Vol. 5, No. 6, 1969.

2. Van Dyke, M. Metody Vozmushcheniy v Mekhanike Zhidtosti (Methods of Disturbances in Fluid Mechanics). Moscow, Mir press, 1967.

3. Volkov, Yu. S. Spectra of Changes in Speed and Temperature of an Air Flow Over a Rough Sea Surface. Izvestiya AN SSSR, Fizika Atmosfery I Okeana, Vol. 5, No. 12, 1969.

4. Zubkovskiy, S. L. and T. K. Kravchenko. Direct Measurements of Several Characteristics of Atmospheric Turbulence in the Layer Near the Water. Izvestiya AN SSSR, Fizika Atmosfery i Okeana, Vol. 3, No. 2, 1967.

5. Kitaygorodskiy, S. A. Small-scale Interaction of Ocean and Atmosphere. Izvestiya AN SSSR, Fizika Atmosfery i Okeana, Vol. 5, No. 11, 1969.

6. Milne-Thompson, L. M. Teoreticheskaya Gidrodinamika (Theoretical Hydrodynamics). Moscow, Mir press, 1964.

7. Monin, A. S. and A. M. Yaglom. Staticheskaya Gidromekhanika (Statistical Hydromechanics). Part 1. Moscow, Nauka press, 1967.